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GEOLOGY OF THE REGION ABOUT NATAL, RIO GRANDE DO NORTE, BRAZIL.

(PLATES XV.–XXII.)

BY OLAF PITT JENKINS.

(*Received May 29, 1913.*)

INTRODUCTION.

The state of Rio Grande do Norte is one of the smallest in Brazil; it has an area of 57,485 square kilometers, and lies wholly within the tropics. The climate, topography and geology of this state may be taken as a type of the geology of the northeastern coast of Brazil.

Topographically the region is one of rather low relief, the climate is semi-arid, and in places the soil is thin. The general geology is simple, consisting of an old series of crystalline rocks, probably of Archean age, over and upon which rests a coastal belt of Cretaceous or Tertiary sediments having a width of about thirty kilometers. There are some mountains of fair size in the interior, but they are nearly all of granites or other crystalline rocks. None of these mountains lie within the area discussed in the present paper.

In 1909 I published in the *Bulletin of the Geological Society of America* a paper on the geology of the Northeastern Coast of

Brazil that included all that was then known of the geology of the coast of Rio Grande do Norte from Natal to the southern edge of the state. That paper contained a sketch map showing the coastal belt of sedimentary rocks.

The work of Mr. Jenkins, done in 1911, has added much to our knowledge of the region, especially to the north of Natal, and it has definitely located the landward margin of the sedimentary beds.

It has also disclosed an unconformity in the sedimentary beds that seems likely to clear up the long standing question in regard to the existence of the break between the Cretaceous and the Tertiary in this part of South America. Some of my own geological observations made in 1911 have been incorporated in Mr. Jenkins' paper, while specimens of crystalline rocks from near Baixa Verde, examined microscopically and described by Mr. Jenkins, were collected by Mr. Earl Leib another member of the expedition.

J. C. Branner,

Director of the Stanford Expedition to Brazil.

Stanford University, California,
May 6, 1913.

Introductory.

In the summer of 1911 the Stanford Expedition to Brazil made its headquarters for six weeks at Natal, in the state of Rio Grande do Norte, 5° 45′ south latitude, 35° 12′ west longitude. During this time most of the members of the party were engaged in collecting zoölogical material. Occasional inland trips were made which gave means for determination of geological data. These trips were along three lines, each of which went far enough into the interior, about forty or fifty kilometers from the coast, to reach the crystalline series of rocks:

1. To the northwest by railroad—"Estrada de Ferro Central do Rio Grande do Norte"—to Taipú and Baixa Verde.

2. To the south and southwest by the "Great Western Railway of Brazil," which extends for many kilometers down the coast.

3. To the west by boat up the Rio Jundiahy to Macahyba.

The ways by rail afforded the gathering of geological data by notes taken from the car windows, and by material collected at the various places where the train stopped. At certain points the party remained for several days and from these points horseback trips and walks gave data of more detailed character. These side trips were made around the towns of Taipú, Itapasaroca, Ceará-Mirim, and Extremoz.

A horseback trip from Carnahubinha to Macahyba and back into the interior, followed one of the contacts and gave familiarity with the general character of the country.

Thus the map was compiled from compass traverses, notebook sketches, railroad surveys, hydrographic charts, and the map of the region made by Crandall and Williams to the scale of 1 to 1,000,000.

Topographic Relief.

The Coast.

The vast stretches of sand are the most striking feature in the region about Natal and the northeastern coast of Brazil. The wind blows constantly up the coast to the northwest, driving the sand before it, filling up the stream mouths, banking against the low shrubs, sometimes planted by the people along the coast, forming a great range of sand-hills parallel to the coast. It is swept back by diverging currents over the low interior country for many kilometers covering up the soil and rocks, filling up the broad valleys, and forming long parallel sand-dunes all pointing to the northwest.

Underlying sandstones outcrop along the coast at various points. They form generally perpendicular cliffs from a few feet to about seventy-five feet in height as those of Barreiras do Inferno. These sandstones contain iron which is concentrated in certain places, hardening them into limonitic rocks that ring like steel when struck with the hammer. Sometimes all the pebbles of a portion of a beach are cemented together in this manner, forming a prominent point along the coast. These low points of dark, red-brown rocks and parti-colored cliffs of sandstone break the continuity of the white sand beaches. The wind, sweeping up the coast, banks the

sand at the points, forming a smooth straight shore line up to the south side, and leaving a little cove on the north side. Tall cocoanut palms may grow along the shores of this cove, waving over a tiny fishing village and a little church. The fishermen can here embark in their *jangadas* with greater ease than out on the windy south side of the point. Usually into such a cove a stream flows, if not, the people get their water by digging into the sand of the coast and a bubbling supply of sweet water is easily obtained. Sometimes one may see fresh water coming up through the sand right where the waves wash.

The sand is blown into the river mouths and tends to fill up their south sides, causing the streams to cut into their northern banks, where the sand is being swept away. Thus many of the streams turn, just before reaching the sea, and flow northward as they enter the sea. A view of a river's mouth from a vessel at sea shows a high range of sand-dunes on the south side, while to the north the country is low and rises gradually farther up the coast, where it culminates at another river mouth.

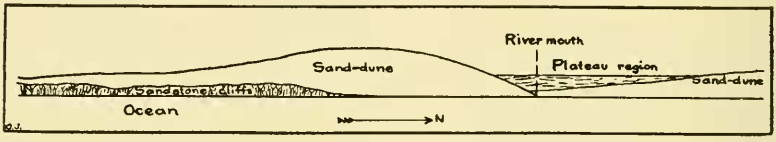

FIG. 1. A view from a steamer towards a river mouth, showing how the sand piles up at the south side of the stream.

There is often a hardened sand-beach in front of the mouth of such a stream, lying in a straight line parallel to the shore, where the fresh water meets the sea water. These stone reefs[1] have the general appearance of an ordinary sand bar, but they are hardened almost to a quartzite, and are difficult to break with the hammer. They contain white quartz sand and marine shells now found along the beaches. Often these stone reefs are found with no apparent stream behind them, but if one goes farther back into the country one may find an abandoned stream channel which formerly had an outlet behind the stone reef.

[1] J. C. Branner, "The Stone Reefs of Brazil," *Bul. Mus. Comp. Zool.*, Geol. Ser., VII., Cambridge, 1904.

The sea is shallow along the coast, and one sees this especially when watching the natives setting their *jangadas* afloat by pushing them along the wide, gently sloping beaches. Often at the end of

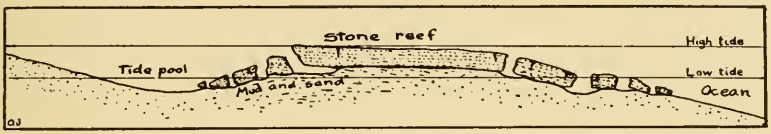

FIG. 2. General cross-section of the sandstone reef at Natal, Rio Grande do Norte.

one of the prominent points, as that of Pirangý, it may be noticed at low tide that the rocks extend for a considerable distance and then an organic reef, containing corals and other marine animals, continues far out to sea, forming a flat shelf for some distance. These organic reefs do not occur near shore, for the waves are full of sand, scooped up from the shallow bottom. The ships cannot come near shore, except through certain channels as that of Natal, where the animals that make up the reefs cannot live on account of the fresh water from the river.

The Valleys.—The most striking feature about the river valleys is their extreme width in comparison to their shallow depth. A small stream like the Rio Ceará-Mirim may flow through a valley two and a half kilometers wide not much more than fifteen meters below the surrounding region. The banks which fringe the wide valleys expose red iron-sandstones, covered with sand or a sandy soil. The valley alluvium is a darker black sandy deposit. The whole floor of the valley is flat, with a sluggish stream flowing down its center, bordered by swamps. The natives, whose mud houses are scattered or clustered in villages along its low sides, use it to advantage and cover most of the valley with their banana, corn, cotton, and sugar-cane fields. In some places, such as Ceará-Mirim, the region is very fertile and a growth of shrubs, trees and *carnahuba* palms covers the valley.

The valley, on the side of which Natal is situated, is about six kilometers wide, but most of this territory is silted up by mangrove swamps. The sea enters it and at high tide flows up to Macahyba

at a distance of about thirty-five kilometers, and returns at low tide. This action is utilized by the people who travel up and down the river only by tides. The present silting up of this great channel and many others like it is extremely interesting because it shows a sunken coast. The sea has intruded into the stream channels and later it has been driven out by the deposition of silt.

The Plateau Region.

The surrounding region is a low, sandy, gently rolling plateau covered with shrubs not much over two and a half meters in height. The small scrubby rubber tree is its typical plant. Farther back into the interior the hills become a more prominent topographic feature,

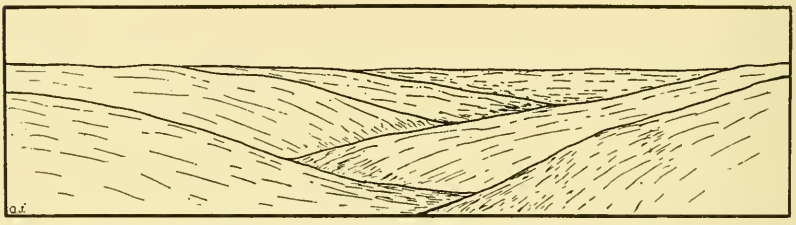

FIG. 3. Topography, looking from Taipú, in the rolling hills of the interior, towards the flat plateau region along the coast, Rio Grande do Norte.

for they are in the crystalline series of rocks. As one travels over the plateau region, its flatness appears unbroken, but occasionally

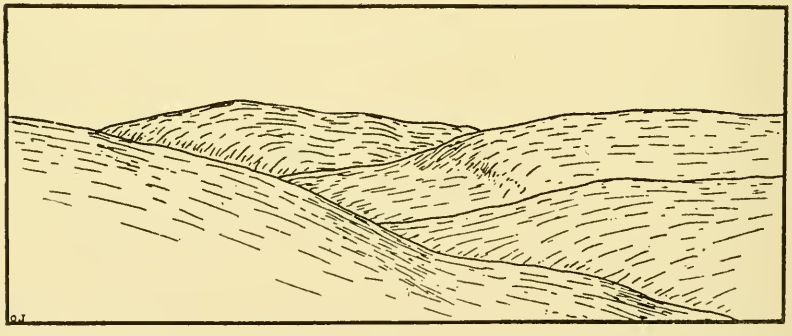

FIG. 4. Topography, looking northwest from Taipú in the rolling hills towards the higher, interior country, Rio Grande do Norte.

one comes upon the border of a wide valley with unexpected groves of *carnahuba* palms, fields of sugar-cane and bananas. A village with its quaint church, set on the upland, looks out on the fertile area while all the surrounding country is as dry and arid as a desert.

The farther one goes into the interior the more arid the country gets. The river valleys diminish rapidly in width, and low hills of crystalline rocks are rounded almost to flatness by age and decomposition. The granites tend to stand out as huge rounded domes, carved and grooved from weathering, while the gneisses and schists form the general base-level plain. The whole region reminds one of the deserts of Arizona with its dry, warm atmosphere, its cacti and desert shrubs, and its lack of water.

It is in a belt about ten or twenty kilometers wide along the coast that the rains have their most decided effect. This region is covered with numerous small fresh-water lakes. Some of them are connected with the ocean and some are not. In times of great rains they overflow and connect with each other. In times of drought some of them dry up completely, as Logoa Secca near Extremoz, a mere depression now which is said to have been full of water forty years ago. Often the lakes seem to have no outlet nor inlet, but if they are examined more closely they are found to be fed by springs occurring along the border just between the impervious clayey iron-sandstones beneath, and the loose wind-blown sand-dunes above. This was especially noticed in the case of Logoa Bom Fim, about thirty-eight kilometers south of Natal. Villages are scattered along the borders of these lakes and each has its cocoa-palm grove. The people are very poor and live on the little they are able to raise and the fish which are caught in the lakes. Other lakes are formed in the river valleys dammed in at the mouths by sand bars on the seacoast. These regions are the most fertile of all. Paparý is a typical example of such a place.

Areal Distribution of the Formations.

The sketch map of the region about Natal, given at the end of this paper, shows best the general distribution of the formations.

In the interior the rocks are crystalline: granites, gneisses, schists, shales, quartzites, and various forms of intrusive dikes. At Macahyba an engineer, who had been far back into the country, reported marble at a distance of about one hundred and sixty kilometers from the coast. This marble was said to have been like that found near Quixadá in Ceará, at the same elevation and relative location. The granitic rocks which are nearest the coast, in the region which this paper deals, occur at Macahyba, for here the river cuts deeply through the sedimentaries and exposes the older series.

Overlying the crystalline series are beds of fossiliferous limestone, lying almost horizontally, or dipping about 5° southeast, towards the coast, in layers of a few inches to a foot or more in thickness. This series is not well exposed. The principal localities for the exposures are at the railway cuts and at the quarries made in the limestones where they come to the surface along the sides of the valleys. Following along the contact of the granites with the sedimentaries one may find occasional indications of limestone on the surface. There seems to be a belt of this limestone, left from the great erosion the country has undergone, about ten kilometers in width. A few pebbles of limestone were found on the surface not far from Taipú, thus indicating a greater extent of the limestones in previous ages.

Unconformably overlying the limestones occurs an unfossiliferous iron-sandstone and clay series of generally unconsolidated material. The beds of this series are hard to distinguish, but they also seem to lie horizontal or to dip gently towards the coast. They extend in a belt about thirty kilometers in width along the coast. They are best exposed as sea-cliffs.

The wide river valleys contain a deep deposit of alluvium. This is an important factor in the geology of the country for these deposits are found to contain marine shells, showing the valleys were once filled with water from the sea, and later completely silted up. This process of silting-up is at present at work in some rivers as Rio Jundiahy and Rio Potengý, where it occurs about twenty-five kilometers inland. It is a mark of a submerged coast.

Over all the other formations a vast amount of sand is at present

being deposited along the coast, blown inland by the wind. The sand tends to fill up the river systems, for they are the lowest places. In time of drought the sand sometimes is able to gain complete control over some of the streams, stopping them up entirely. In time of great floods the water clears its channel again. A good example of damming by sand is the valley of Extremoz, where

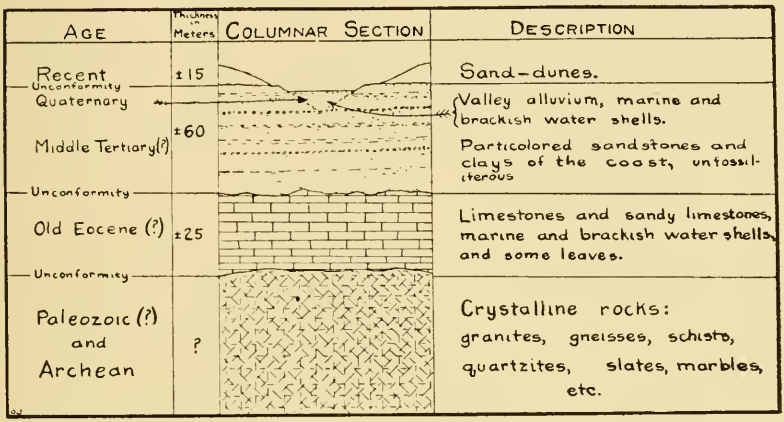

Fig. 5.

sand-dunes are heaped in the valley in longitudinal rows, while at its mouth is a great sand bank, twenty-five to thirty meters in height, lying across it at right angles. About fourteen kilometers inland Lake Extremoz lies in the forks of the old river channel, dammed in by this wind-blown intrusion.

Description of the Contacts.

The limestones lie unconformably on top of the old crystalline series. The contact was plainly seen at Alvoredo, about five kilometers north of Macahyba, in the bed of the Potengý River.

The sandstone and clay series lies unconformably on top of the limestones. At Jacoca, five kilometers southwest of Ceará-Mirim, the contact was observed in the limestone quarries. This showed the fossiliferous limestones in clearly defined beds, six inches or a foot thick, lying horizontally, with the sandstones rest-

ing unconformably on top. This unconformable contact is distinctly marked at these quarries and was carefully studied; photo-

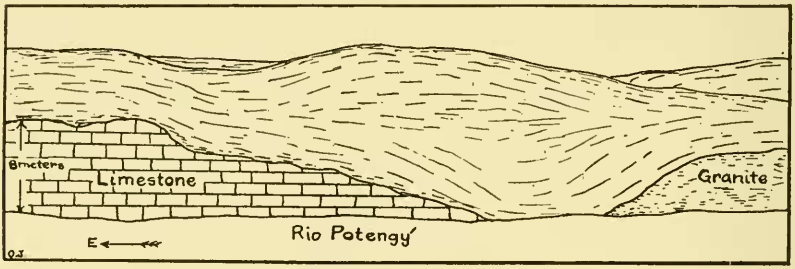

FIG. 6. An exposure along Rio Potengý showing the contact between the horizontal, fossiliferous limestones and the granites. Looking south, near Alvaredo, Rio Grande do Norte.

graphs were taken and material collected. At the point of contact the sandstone is very black, probably carrying manganese. Above this the sandstone has a soft white character, while on top lie the

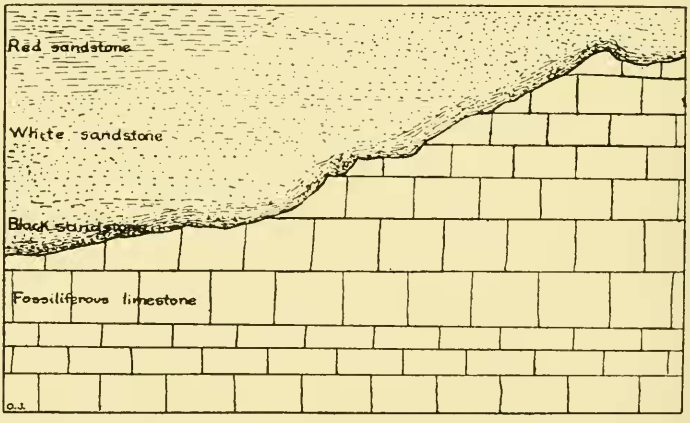

FIG. 7. Diagram made from a photograph of the unconformity between the fossiliferous limestones and the sandstone and clay series as exposed in a quarry at Jacoca, five kilometers southwest of Ceará-Mirim, Rio Grande do Norte.

red iron-stained rocks so common over the country. On the surface of the ground are loose boulders of the iron-rock. The bedding of the sandstone is not very clear, as in most localities, but has the general appearance of being horizontal.

The relation of the sand-dunes to the sandstone is clearly defined along the sea-cliffs. The older æolian deposits of sand lie cross-bedded on top of the horizontally bedded sandstone and clay series. Above these are blown newly formed sand-dunes.

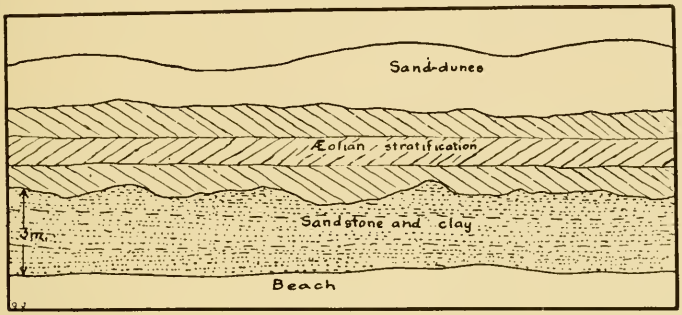

FIG. 8. Diagram of the bluffs at Ponte Negra, Rio Grande do Norte, showing the old æolian stratification with the newly formed sand-dunes lying on top.

The alluvial deposits are extensive, filling the wide river channels.

DESCRIPTION OF THE FORMATIONS.

The formations are described in this paper in the following order:

1. The crystalline rocks, probably Archean.
2. The limestones, of late Cretaceous or early Tertiary age.
3. The iron-sandstones and clays, which are later than the limestones.
4. The alluvial deposits.
5. The sand-dunes.

The Crystalline Rocks.

The railroad extends twenty-eight kilometers west of Taipú to Baixa Verde. The rocks of this region are crystalline, and a study was made of them here. Beyond Baixa Verde one or two kilometers, new railway cuts expose fresh specimens of these rocks, showing something of their general relation to each other. This part of the paper has been taken freely from the notes of Dr. J. C. Branner and Mr. E. Leib. Slides, made from the rocks collected, have been studied and the following report is submitted.

Decomposition has had a marked effect in leveling down this region, so that the natural exposures are only in the shape of flat bosses and exfoliated boulders. Mound-shaped hills, as that of Torreão Peak, which is about seventy meters high, lying three or four kilometers northwest of Baixa Verde, are composed of granitic rocks. On their surface are scattered great boulders of exfoliation, while at their base are bare, flat exposures of other crystalline rocks, giving to the whole the appearance of glaciation.

In all the railway cuts it was noticed that dikes of granites and pegmatites cut through micaceous schists. These dikes vary in width from one to thirty meters, sometimes following the plane of schistosity and sometimes cutting across it. Often one dike inter-

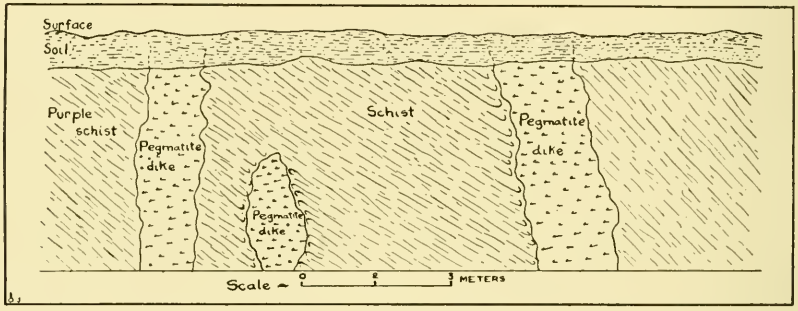

FIG. 9. Diagram of railway cut near Baixa Verde, Rio Grande do Norte, showing how the dikes intersect the schists and how the topography is unaffected by these.

sects another. These dikes and schists do not show in the topography; all are eroded and decomposed to the same surface level.

The following are descriptions of the rocks collected.

Quartzitic Arkose.—This specimen was collected near Taipú, kilometer 53. It outcrops in the region of dikes and schists. The rock is a medium-grained quartzitic arkose containing some minute cavities. Under the microscope the grains show that they are irregular in size and angular to subangular in shape. They are principally fragments of quartz, plagioclase, microcline, and orthoclase, all cemented firmly by opal. Chalcedony occurs as a secondary mineral, filling the minute cavities.

Quartz-Biotite Schist.—This was found at kilometer 49.5 near the place where the railroad crosses the Ceará-Mirim River, not far from Taipú. The rock is dark-colored, hard, rather fine-grained, containing quartz and biotite in great abundance. Its general appearance indicates that it may have been derived from some old sedimentary series. A slide shows quartz and biotite to be abundant as cemented grains. The feldspars are cloudy and hard to distinguish. Magnetite is scattered through the rock. There is some hornblende and tourmaline present.

Biotite-Schists.—In the cuts west of Baixa Verde granites and pegmatites cut through biotite-schists. Fresh specimens of these schists have a shiny, black or purple color. When weathered a little, the schists turn a brownish tint. In one specimen collected at the sixth cut beyond Baixa Verde, the following minerals appear in the slide: biotite in great abundance, quartz rather prominent, a considerable quantity of plagioclase and orthoclase, only scattering amounts of apatite and magnetite, and some garnet. Another specimen of this biotite-schist, which is partly weathered, shows some sillimanite.

Granite-Aplite.—A specimen from a dike cutting through the biotite-schists in the fifth cut west of Baixa Verde is a medium-grained, pinkish-white granite-aplite. Quartz grains are distinct. Muscovite and biotite are easily recognized in the hand specimen. With the microscope the following minerals were found: orthoclase and quartz are abundant; plagioclase and microcline are rather prominent; there is a quantity of titanite; both muscovite and biotite are present; some garnets and specks of magnetite are scattered through the rock.

Granite-Pegmatite.—Occurring as dikes, breaking through the biotite-schists, are granite-pegmatites. Some of them are graphic granites, and in some the quartz is scattered through irregularly. All of them are a light pinkish, decomposing to an almost whitish color, the feldspars changing over to sericite. A slide shows the following minerals: orthoclase, plagioclase, and quartz in abundance; microcline, rather prominent; biotite in patches; and tourmaline of a very dark variety. In one pegmatite there occurs a vein of red-

brown chalcedony. This may indicate that the schists were derived from old sedimentary rocks.

Granites.—The larger dikes which cut through the schists are usually granites. These rocks are medium-grained with a pinkish-gray color due to pink color of the feldspars. In one specimen the following minerals are in the slides: quartz, plagioclase, and orthoclase in great abundance; hornblende and magnetite prominent; titanite, garnet, and pyrite in smaller amounts. Other specimens from one of the larger dikes show a quantity of microcline and in addition to the other minerals zircon and apatite. In a specimen which came from a decomposed portion of the granites, sericite is prominent. The feldspars decompose leaving the mica flakes and the quartz grains prominent at the surface.

Log of Well at Baixa Verde, Rio Grande do Norte.

The following is a log of a well with a six and three-fourths inch bore taken at Baixa Verde, Rio Grande do Norte, at kilometer 84, elevation 162 meters.

	At — meters.
Gneiss	5
Dark granitic schist	10
Granitic rock, hard	15
Gneissoid granite	18
Schist	24
Fresh, hard granite, pinkish	39
Gneissoid granite, with dark streaks	43
Hard, gneissoid granite, pinkish	45
Greatest depth reached	46

From the above well, bored in crystalline rocks, it is clear that the gneisses, schists, and granites are intermixed and intergrade. This is typical of the way in which they occur in this country,—first one and then the other, with perfect gradation.

The Limestones.

General Description.—The limestones vary in color from light yellow to pure white. Some of the beds are bluish in appearance

and are hard and siliceous. Other beds are softer and limy, scattered through with sand grains, while others are almost sandstones. At the quarries, where the beds can best be studied, the more siliceous parts are cast away and the limy portions put in the kiln. The limestones usually show indications of fossils by small cavities and poor casts of shells and plants, but actual remains of animals themselves were not found. Metasomatic replacement of the shells by other minerals was not found to occur, although large irregular cavities give place for the deposition of silica in the form of quartz geodes.

A slide of the limestone obtained near Itapasaroca was studied. The following minerals in irregular grains were found in it: quartz orthoclase, microcline, and mica (biotite and also probably muscovite). The main part of the rock is a fine-grained carbonate containing both calcite and dolomite. Chemical tests showed some portions of the rock to be more dolomitic than others. It may be called a *magnesian limestone.*

Detailed Description.—The following are the principal localities studied where the limestone series is exposed in cuts:

1. Itapasaroca,—railway cut at kilometer 45, exposing limestone beds containing fossil casts of shells and plants.

2. Ceará-Mirim,—a quarry near kilometer 35. Limestone is exposed but there are no fossils.

3. Jacoca,—four kilometers southwest of Ceará-Mirim two quarries expose fossiliferous limestone beds. Here the line of the unconformable contact with the red-sandstones may be definitely traced.

4. Masaranduba,—fifteen kilometers north of Macahyba. A quarry is on the bank of one of the inlets to Lagoa Extremoz. There were only bare traces of fossils in the limestone beds.

5. Desterro,—seven kilometers north of Macahyba. A quarry in sandy fossiliferous limestone.

6. Alvoredo,—exposure on the bank of Rio Potengý, three kilometers north of Macahyba. Here limestone, with faint traces of fossils, lies directly on top of the granite, also exposed in the stream.

All expose practically horizontal beds, which have the general tendency to dip towards the ocean to the southeast. These lime-

stones are all obviously in the same horizon. Although each locality seems to have its own specific character and fossils, yet they all are more or less similar and are probably different facies of the same horizon.

Itapasaroca.

Half a kilometer beyond Itapasaroca, at kilometer 45, the railroad cuts through beds of limestone. This cut exposes four or five meters of the series. In the material thrown out of the cut, impressions of shells are abundant. In some of the rocks figures of plants, such as palms, occur. No good fossils could be found, but there is an abundance of material. The rock is a light or buff color. It occurs in beds of a foot or six inches in thickness. The strata stands almost horizontal or dipping slightly towards the sea to the southeast. In this exposure some of the beds have been slightly compressed into waves of about a meter in height. Beyond this cut is the old valley of Ceará-Mirim, and on its opposite side are the crystalline rocks, at a lower level than the limestones.

Ceará-Mirim.

About two hundred meters up the railroad from kilometer 35, near the town of Ceará-Mirim, a lime kiln is situated on the south side of the railroad track. One hundred meters or so up the hill from this is a limestone quarry. The hill forms the bank of the valley of Rio Ceará-Mirim, and the railroad skirts its edge. The beds at the quarry are practically horizontal, four meters being exposed in the cut which lies about 28 meters above the railroad track, whose elevation at Ceará-Mirim station, not far off, is 31.5 meters. Thus these beds lie about 60 meters above sea level. The material of the beds is very hard and limy. The fossils, which formerly must have been in this rock, have been completely obliterated by circulating waters. It was noticed at this quarry that the decomposition of the beds was aided by the action of roots of the shrubs, which opened cracks in the limestone allowing surface waters to pass readily downward. These waters carry with them iron from the sandstones above and deposit it in the cracks, leaving the

white limestones marked with streaks of red-brown. The hill above these beds is covered with thick scrubby vegetation. The soil is red and sandy, and lumps of the red iron-sandstone are scattered over the surface, showing that the sandstone beds lie above the limestones.

Jacoca.

Four kilometers southwest of Ceará-Mirim is situated the village of Jacoca in the valley of one of the inlets of Lagoa Extremoz. On the northern bank of the valley are two limestone quarries. These expose about four meters of limestone beds overlain, in certain places, by as many meters of the red-sandstones. The contact between these two series of rocks is irregular and unconformable. Each limestone bed is about a third of a meter in thickness, making a total of twelve beds. These vary in their content of lime and silica. Poor impressions of fossil shells are still left in the rock. The material is almost pure white in color and is a magnesian limestone with sand grains scattered through it. The contact line is irregular and shows that the limestones once underwent the reduction of erosion before the sandstones were laid on top. Between these beds and the sandstones is an area of black material which is probably a deposition of manganese. Above these are whiter sandstones of soft character, and still higher up are the red sandstones, characteristic of this latter series. On the surface of the ground are scattered boulders of the red iron-rock.

Masaranduba.

The village of Masaranduba lies in the valley of Rio Guargirú, an inlet to Lagoa Extremoz, on a road which leads from Macahyba to Ceará-Mirim, about half way between these two cities. One kilometer east of Masaranduba is a limestone quarry situated on the bank of the valley. The beds in this place are practically horizontal and unaltered. The exposure is four or five meters high. The material is of very pure limestone. It is white, and almost devoid of any fossil remains. On the hill above are loose pebbles of both limestone and iron sandstone.

PROC. AMER. PHIL. SOC., LII. 211 K, PRINTED SEPT. 16, 1913.

Desterro.

On the northern side of the broad valley of Potengý, north of Macahyba and near the place of Desterro, are some surface indications of limestone. Holes, a meter in depth, have been dug in prospecting for limestone. The material in these dug-outs is a yellow sandy limestone containing fossils, evidently in the same series as the other limestones.

Alvoredo.

On the southern side of the valley of Potengý, near Alvoredo and north of Macahyba, where the river cuts into its bank, is an exposure of about eight meters of limestone beds. These are horizontal. The material is the same as in the other localities with more sand and with more fossil impressions. Up the river, thirty meters or so, is a granite mass in place, standing about five meters high. Although bushes and soil hide the actual contact of the limestones with the granite, yet it was clear that the beds lapped directly on top of the crystalline rocks.

Fossils from the Limestones in the Region About Natal, Rio Grande do Norte.

The material collected from the fossil localities of the limestones in the region about Natal, Rio Grande do Norte, is exceedingly poor. Only casts and impressions could be found. In all they consisted of about a dozen different species of marine or brackish water shells, one questionable crustacean, and some plants, chiefly palm leaves. The limestones contained, in most cases, just enough sand grains to ruin the detailed character of the impressions. There were no definite horizon-marking fossils, but they all have the general appearance of being Tertiary, probably in the lower part of the series.[2]

[2] A collection of the fossils from the Rio Grande do Norte limestones was sent to Professor Gilbert D. Harris, of Cornell University, for examination, and he writes as follows of it under date of December 20, 1912: "Many of your specimens I judge belong to undescribed forms. Of the generic types I see none that might not possibly be anywhere from Cretaceous to recent, except perhaps the fragmentary impress of an Arca. None appear to

This material looks very much like that collected at Ponta de Pedras, which is supposed to be Eocene.[3]

The only fossil which is common to both these localities is *Cardium soaresanum* Rathbun.

The general character of the beds shows them to have been deposited in an estuary. This indicates that such a condition existed then as now along the coast of Brazil, *i. e.*, a sunken coast.

Cardium (Criocardium) soaresanum Rathbun.

(Plate XX., Figs. 2 and 2a.)

Cardium soaresanum Rathbun. *Proc. Bost. Soc. Nat. Hist.*, Vol. XVII., Rathbun, "Cretaceous Lamellibranchs of Pernambuco, Brazil," pp. 253–255, 1874.

Cardium (*Criocardium*) *soaresanum* Rathbun. Extract from *Archivos do Museu Nacional do Rio de Janeiro*, Vol. VII., C. A. White, "Cretaceous Paleontology of Brazil," p. 90, Pl. VI., Fig. 6, 7, 8, Wash. 1888.

Cardium (*Criocardium*) *soaresanum* Rathbun. *Bull. Geol. Soc. Am.*, Vol. 13, p. 47, J. C. Branner, "Geology of the Northeast Coast of Brazil," 1902.

This is the only species that may be identified in all the material collected from the limestones of the region about Natal, Rio Grande do Norte. Numerous casts were found in every fossil locality and are easily recognized by the fine radial ribs, about 22 in number,

be distinctly Cretaceous unless the fragmentary impresses of a broadly turreted form showing some peculiar internal lirations should prove with other material to be a true Nerinæa. The fauna bears some resemblance in its little Chione forms to the Maria Farinha fauna, and though evidently representing a phase I am unacquainted with, I should be inclined to regard it as old Eocene. Still, as I said before there is not a single characteristic form wherewith to prove this statement."

The *Journal of the Academy of Natural Sciences of Philadelphia*, Vol. XV., lately published, has a paper on some fossils found at Trinidad in the northern part of South America. It settles the age of the Maria Farinha, Olinda and Ponte de Pedras beds definitely as Midway Eocene (pp. 32–33). The beds at Itapasaroca look precisely like those of the Midway Eocene beds, and each contains *Cardium soaresanum* Rathbun.

[3] J. C. Branner, "Geology of the Northeast Coast of Brazil," *Bull. Geol. Soc. Am.*, Vol. 13, p. 47, 1902.

each ornamented with minute points on its ridge. The specimens are small, about 12 mm. in height and width, and the thickness of the two valves is 6 or 7 mm. Inside casts are smooth and may be confused with the impressions of the sculptured outside.

Corbula (?) sp. ind.

(Plate XX., Fig. 1.)

This Corbula-like form is not like that recorded from Ponta de Pedras. Most of the specimens were 12 or 15 mm. long and 8 or 9 mm. high, but one specimen is twice that size. The beak is situated about a third the total length from the posterior end. No radial ribs appear in the impressions, but the lines of growth are very plain, standing out in marked relief. At the anterior end there is a raised portion, almost a ridge, running to the beak. The total angle made by the shell, taking the beak as the vertex, is approximately 120°.

This form is easily recognized by its smooth, even form and the distinct concentric lines of growth. It is abundant at the exposure in the railway cut near Itapasaroca, Rio Grande do Norte.

Cerithium (?) Mirimense Jenkins, new species.

(Plate XX., Figs. 8 and 8*a*.)

Many casts and impressions of a *Cerithium*-like form were found at the railroad cut near Itapasaroca, Rio Grande do Norte. The maximum height of the shell is nearly 15 mm. and the width of the lower part is 6 or 7 mm. The angle of the spire is 40° to 45°. Four or five ridges stand out on each half volution, running in the same direction as the spire, and alternate with the ridges on the adjoining volution. Spiral lines, 6 or 7, to each volution, run over the ridges and around the shell, following the volutions, and dividing the ridges into a row of little knobs. There are 6 or 7 volutions, which decrease rapidly in size as they approach the top of the spire. The aperture was not well preserved in any of the specimens collected. In one or two cases it looks as if it were oval-shaped. There is no sign of an extended canal.

This species is easily recognized by its very convex shape and the distinct sculpturing which is on its sides. Delicately ornamented cup-shaped impressions, left in the finer siliceous parts of the limestones, may be easily observed.

Cerithium (?) sp. ind.

(Plate XX., Fig. 4.)

At the locality near Desterro were found impressions of a *Cerithium*-like form unlike those found at the other localities. Length, 10 mm. to 12 mm.; width of last volution, 3 or 4 mm.; angle of the spire, approximately 25°. The volutions are about 8 in number, each convex in profile, and ornamented with spiral, slightly dotted lines following around the volutions. The aperture was not preserved in any of the specimens.

Turritella (?) Jacoquea Jenkins, new species.

(Plate XX., Figs. 7 and 7*a*.)

A broadly turreted form. The length is 25 or 30 mm. The width of the last volution is 12 or 15 mm. There are 8 or 9 volutions on the spire which comes to an angle of approximately 40°. Each volution is slightly convex in profile. The ornamentation is not distinctly visible on such poor material. There may be some sort of ornamentation following the center of the volution.

Many poor casts and impressions of these shells were found in the sandy limestones of the quarries at Jacoca, four kilometers southwest of Ceará-Mirim, Rio Grande do Norte. Inside casts show a double spiral coil following the volutions.

It is difficult to tell from such poor material whether or not this is a *Turritella*. If it proves to be *Nerinaea* it may place the age of the rocks in the Cretaceous. However this species is easily recognized by its broad form and may be of use in later correlation.

Turritella natalensis Jenkins, new species.

(Plate XX., Figs. 6 and 6*a*.)

A small, slender shell about 35 mm. long. The longest found was 50 mm. The diameter of the last volution is about 6 or 7 mm.

The angle of the spire is about 12°. The shell has from 16 to 22 volutions, usually 18 or 19, ornamented with two rows of tiny knobs situated at the borders of the volution, close to the suture. The row on the upper side is more prominent and becomes more so the nearer it approaches the top of the spire. In some of the younger or smaller specimens it stands out as a knobby ridge. There is another rather distinct row of knobs or points following the center of the volution. The material is so poor that it is difficult to determine anything further about the ornamentation except that it varies a little among different specimens. Some of the knobs are almost spines, appearing as little points, 6 or 8 on each half volution.

This form is not *Turritella elicita* as given by White, found at Maria Farinha and Ponta de Pedras. It differs principally in the ornamentation, having rows of points instead of ridges on the volutions. Also these rows are not situated in the same positions as in *Turritella elicita,* nor is the angle of the spire nearly so great.

The original shells were never found, so the casts were studied principally from wax molds made from them.

Associated with these fossils were *Cardium soaresanum* Rathbun, some *Cerithiums,* and a *Corbula*-like form. Apparently on top or interbedded with strata containing these were found casts of plant fragments, such as palm leaves.

Numerous casts of these *Turritellas* were found near Itapasaroca, Rio Grande do Norte, in the limestones exposed by the railway cut. In most of the other limestone exposures of this region these same forms occur.

Other Fossil Remains.

(Plate XX., Figs. 3, 5, and 9.)

Other fossil remains were found in the limestones. One appeared to be a portion of a *Pholas*-like shell; another, probably an *Ostrea* (Fig. 3). A larger bivalve, *Cardium*-like, about 25 mm. long and 20 mm. high, was rather common. A small *Cerithium*-like form (Fig. 5) with a sharp, smooth spire, making an angle of 40°, was found and is probably different from the other Cerithiums. A few specimens of a small gastropod (Fig. 9), something like *Natica,*

occurred in some of the beds. A small portion of a segmented animal, probably a crustacean of some kind, is also in this collection. The plant remains are principally impressions of fragments of palms and leaves of other plants. The principal importance of these plants lies in the fact that they indicate estuarine conditions of deposition.

List of Fossils from the Limestones in the Region about Natal, Rio Grande do Norte.

	I.	J.	A.	D.
PELECYPODA:				
Cardium soaresanum Rathbun	*	*	*	*
Cardium (?) larger specimen	*	.....	.....	.....
Corbula (?) sp. ind.	*	.....	.....	.....
Ostrea (?)	*	.....	.....	.....
Pholas (?)	*	.....	.....	.....
GASTROPODA:				
Cerithium (?) *mirimense*, n. sp.	*	.....	.....	.....
Cerithium (?) sp. ind.	.....	.....	.....	*
Cerithium (?)	*	.....	.....	.....
Natica (?)	*	.....	.....	.....
Turritella (?) *jacoquea*, n. sp.	.....	*	*	.....
Turritella natalensis, n. sp.	*	.....	.....	.....
Crustacean (?)	*	.....	.....	.....
PLANTS:				
Palms, etc.	*	.....	.....	.....

Explanation.—I. is the railroad cut near Itapasaroca; J. is the quarry at Jacoca; A. is the locality near Alvoredo; D. is the outcrop near Desterro.

The Sandstone and Clay Series.

The sandstone and clay series which overlies the limestone is easily recognized by its peculiar character and color. It is a soft quartz sandstone intermixed and interbedded with sandy clay and with small pebbles up to boulders the size of a man's head. Its color is usually a brick red, but varies from white to a dark red-brown; red, blue, yellow, and lavender are some of the commoner shades. These sandstones must carry a large quantity of iron, for its presence is very noticeable at surface exposures. Along the sea-cliffs the leaching and concentrating is marked. It often forms perpendicular bands in the material, alternating hard red columns

to soft white ones, easily washed out by the sea. The harder portions of the concentrated limonitic deposits often form irregular shapes, leaving small holes and caves in which bats sometimes live. These more resisting portions may sometimes be left standing out as mere columns, breaking off before the beating of the waves. When these irregular rough pieces collect together they cement one to another and form a solid rocky point. So well is this cementing process carried on, that it is often hard to find a single loose pebble around a promontory. The soft leached parts of the cliffs are washed away and thrown up on the beach, where the wind carries them back over the country in the form of sand-dunes.

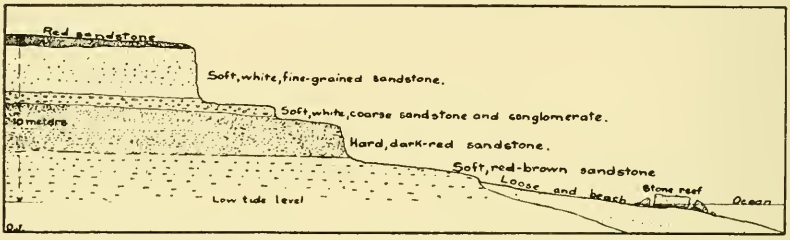

Fig. 10. A typical section of the sandstone series as exposed in a stream cut eight kilometers south of the fort at Natal, Rio Grande do Norte.

All along the coast from Natal to Busios the bed rock which is exposed is that of the sandstone series. The points named on the map and many other smaller ones are all made up of hard red-brown iron-cemented sandstones, which occur in irregular blocks broken down from an adjoining low cliff. In some places, as about eight kilometers south of the Fort at Natal and a hundred meters from the beach, the sandstone series has been cut through by a stream into deep, extremely narrow ravines. The beds are almost horizontal and the general surface is level, but these peculiar cuts break the surface, making it almost impassable although they are not much more than ten meters deep. It is a sort of Grand Canyon type of erosion. In such places bedding may be distinctly observed and the nature of the strata easily studied. The beds vary in texture from a fine soft sand or a clayey sand to a coarse conglomerate. These are interbeded, all carrying more or less clay, and varying in

hardness but usually rather unconsolidated. The amount of iron in the rocks seems to determine their color and also their hardness. These colors vary from white through all sorts of shades, especially red, brown, purple and yellow. Sometimes they are banded or streaked. Sometimes, as at Barreiras do Inferno, certain beds have concentrated all the iron. At this place the undermining action of the waves causes huge iron-sandstone blocks to break off and drop from a ledge three meters thick and these form a pile of irregular shaped boulders along the coast, all cemented together. These cliffs extend for about a kilometer along the coast. Their maximum height is twenty-five meters and they are perpendicular or sometimes overhanging. It is very difficult to pass back of them on account of the deep ravine structure formed there.

Just south of Barreiras do Inferno there are caves formed in the sandstone, which is harder and stands up better than in other places. These caves are formed by the waves at high tide. One cave was noticed which was one meter high, seven meters wide, and ran back five meters into the rock.

Usually the sandstone bluffs are not much over five meters high and the bedding is invisible on account of the peculiar banded perpendicular leaching. This was especially noticed at Morcego and at Pirangý. Here the iron is concentrated in perpendicular bands or columns, leaving a soft sandy or putty-like material in between. Over these bluffs the sand-dunes rest. Probably the rain, which sinks down through the sand-dunes, is regulated in seepage in such a way as to have this peculiar leaching effect on the beds below.

Farther into the country this sandstone series is easily recognized by its peculiar reddish color, visible especially along the low bluffs which border the wide valleys. Also it is seen where the wind-blown sand is only thinly scattered over the surface of the ground.

In all these beds not a single sign of any organic remains was found.

The vegetation on this series is always poor, scanty, and scrubby in form, sometimes almost entirely lacking.

Alluvium.

The only fertile land of the country is the alluvial deposits. They occur in the wide flat valleys as a black, sandy loam containing a good deal of plant matter. These deposits have been carried down by the rivers and washed in by the sea. In some places as in the river by Natal, this silting up has not yet been finished. Here mangroves act as a sieve for the sediments. In some places they have only left a comparatively small passage for the water, taking up at least four fifths of the entire valley, which is about six kilometers wide. Their many spreading roots retard the flow of the heavily laden water, which drops its load and thus fills up the channel.

Some marine shells were excavated from an irrigation canal made in the center of the valley of Rio Ceará-Mirim, about ten kilometers northwest of Extremoz and thirteen kilometers from the coast. From their preservation they look as if they were of Quaternary age. They occurred about a meter underground. The valley is very low at this point, said to be two meters above sea level. This shows that the sea must have extended up to this point, probably in a long narrow channel filling the river valley, and since then has been silted out, and possibly the country has been raised.

Borings for wells as far up as Carnahubinha bring up shells of the little rock oyster, *Ostrea equestris,* in great abundance. One well was sunk in the alluvium northwest of Carnahubinha, half a kilometer from Rio Jundiahy and at the depth of twenty-one meters a ledge of these oyster shells was struck. An Indian hammer head was also dug up from a depth of three meters in the alluvium, near the river at Carnahubinha.[4]

This is a deposit of more recent age; in fact the deposition may be observed now.

The most interesting thing about the alluvial material is its extreme depth. It extends below sea level. In fact all the valleys show this sunken condition, for they enter the ocean below sea level.

[4] Information obtained from Mr. John Charles Smith at Carnahubinha, Natal, Rio Grande do Norte.

The *carnahuba* palm is a typical plant of the alluvial deposit. It does not grow in the sandstone series.

This alluvial deposit in the valley occurs farther back into the interior than Macahyba. It could be seen as a wide flat depression many kilometers beyond this point, but its limit was not exactly determined.

List of Quaternary Shells from an Excavation in the Bed of Rio Ceará-Mirim, Ten Kilometers Northwest of Extremoz, Rio Grande do Norte.

Pelecypoda.

†1. *Anamalocardia braziliana* Gmelin.
*2. *Arca* (*Scapharca*) *braziliana* Lamarck.
*3. *Arca* (*Cunearca*) *deshayesii* Hanley.
‡4. *Arca* (*Scapharaca*) *pexata* Say var. *holmesii.*
*5. *Cardium muricatum* L.
‡6. *Chione pectorina* Lamarck.
‡7. *Corbula swiftiana* C. B. Adams.
*8. *Divaricella quadrisulcata* d'Orbigny.
‡9. *Phacoides antillarum* Reeve.
†10. *Phacoides pectinatus* Gmelin.
‡11. *Laevicardium serratum* L.
‡12. *Macoma constricta* Bruguiere.
*13. *Ostrea equestris* Say.
‡14. *Pecten* (near *antillensis*).
*15. *Tellina lineata* Turton.

Gastropoda.

*16. *Anachis lyrata* Sowerby.
*17. *Bulla striata* Bruguiere.
*18. *Cerithium algicola* C. B. Adams.
*19. *Cerithium thomasiae* Sowerby.
*20. *Hemifusus mono* Lamarck.
†21. *Nassa vibex* Say.
*22. *Neritina virginea* Lamarck.

Explanation.

* Shells compared with those collected on the Branner-Agassiz expedition to Brazil and identified by Dr. Dall.[5]

[5] W. H. Dall, "Molluska from the Vicinity of Pernambuco," *Proceedings of the Wash. Acad. Sci.*, Vol. VIII., pp. 139–147. April 15, 1901.

† Shells compared with those from collections from Florida. These are also listed in this same paper of Dr. Dall's.

‡ Shells identified by Dr. Dall, November 21, 1912, who says:

"These shells are (except *Pecten*) identical with West Indian forms

now living, most of which also live on the Brazilian coast. The *Pecten* may also be, but we don't happen to have it."

All the rest of the shells are West Indian forms now living. The age of the deposit is probably late Quaternary. The deposit is evidently estuarine, the sea having extended into the old river channel in a narrow embayment. The water was mostly salt, but partly brackish, for *Bulla, Cerithium, Neritina, Corbula, Ostrea,* and possibly *Arca* (making a total of nine species out of twenty-two) are brackish water forms. *Neritina virginea* is sometimes found even in practically fresh water.

Log of a Well at Natal, Rio Grande do Norte.

(Reported by R. H. Soper in a letter of Sept. 21–29, 1912, to J. C. Branner.)

"I give here the log of a well which was drilled about one mile [two kilometers] from the bridge, toward Natal, across the river from Natal, and on the low marshy ground which borders the stream. The figures are from Burgess, the driller whom you may remember as the German who drilled the well in the crystalline stuff at Baixa Verde. He kept samples systematically which I saw and from which I compiled this record.

Meters.	
0–32	All a blackish, sandy, sticky, clayey mud. All contains more or less water which is salty.
32–41	A sandy clay, mixed with pebbles and boulders of quartzite. The largest pebble in the sample was about the size of a hen's egg.
41–42	White fine-grained sandstone.
42–44	Yellowish brown, clayey sandstone.
44–46	Whitish clayey sandstone.
46–50	Fine-grained reddish sandstone with occasional large pebbles of quartzite.
50–55	Dark, fine-grained sandstone with some clay and a little mica.
55–57	Quartzite pebbles with chunks of a mineral which gives a sharp biting taste like sal ammoniac.
57–64	Dark colored fine-grained sandstone which gives place to a hard, coarse-grained sandstone.
64–67	Dark pebbles of quartzite with pieces of hard, coarse-grained, vitrified sandstone.
67–82	A very fine-grained sandstone with considerable clay. Very hard. Comes out wet and black. Is a grayish white when dry.
82–87	A hard, brownish, sandy clay. When wet it was very black and could only be removed from hands with kerosene. Had a bad smell.
87–88	Same as 67–82.
88–94	Same as 82–87.

94–103 Coarse, grayish, clayey sand.
103–107 A brownish and grayish fine-grained, sandy clay which is black when wet.

"I might add that the well stopped here. There was more or less water all the way down but none of a drinkable quality. The name of the place where this well is located is 'Porto do Padre.' Burgess told me that when the tide was high, the level of the water in the well was low and when the tide was down low, the level of the water in the well was up."

The Sand-Dunes.

The action of the sand-dunes on the northwest coast of Brazil is of great importance. It is best studied along the coast for there the waves sometimes cut into the banks and expose dunes of older ages. Cross-bedding is the general form which it takes, distinctly marked, and overlying the soft red sandstone series. The sand is composed almost entirely of white quartz grains. It is blown back from the coast and across the country. It forms long parallel hills of yellowish color across the railroad south of Natal just north of Pitimbú. Here it has been carried from Ponta Negra. This form is common all along the coast in a belt about ten kilometers wide.

An interesting work of the wind and sand was that in the valley Extremoz. At the mouth of the valley, which is about two kilometers wide, there is a bank of sand-dunes some thirty meters in height, completely shutting in the basin. This bank must have existed some time, for a small lake, bordered by cocoa-palms, is nestled in its crest. The valley back of it contains a series of long, narrow freshwater lakes more or less connected end to end, but distinctly separated on their sides by long parallel dunes running lengthwise up the valley, standing almost as high as the surround-

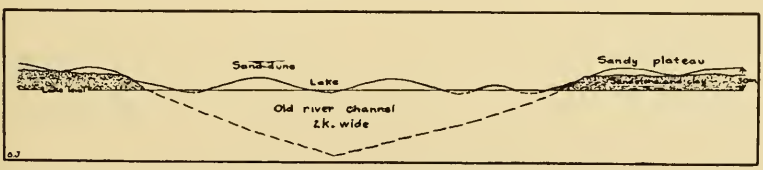

FIG. 11. Cross-section of the Valley of Extremoz, Rio Grande do Norte, showing the system of parallel lakes between the sand-dunes which dam it up.

ing low plateau. These dunes are of old character, dirty, and covered with vegetation. In some places the lakes are round, but usually they are long and narrow. They are bordered by little or no vegetation. Nearby a cocoa-palm grove may stand with its tiny village. This condition continues for ten kilometers up the valley to Logoa Agramara. Beyond there are a few meadows, dried-up ponds, and sand-dunes which close up the valley farther on. Logoa Extremoz is a horseshoe shaped body of water beyond the sand-dunes, situated at the junction of the two old river beds which go to form the main valley. This lake has a tiny outlet which runs into a marsh where it is dried up and sinks into the sand. The village of Extremoz lies on its northern shore and the railroad passes in sight of it. The general appearance of the lake as viewed from the car window was that of a river, not a lake. Further examination showed it to be a lake in an old river channel with two inlets, one at each of the ends of the horseshoe. "The fish fauna of Lake Extremoz is made up of the usual fresh water forms of the region and, in addition, many typical salt water ones, such as *Centropomus, Mugil* and *Gerras,* showing that the lake has been connected with the sea in recent years, though it is said to be cut off by sand hills at the present time."[6] These marine fishes are known to live for years in the fresh water of the tropics but are not known to spawn there. The habit of spawning in sea water is too great to be readily changed. At Ceará-Mirim only fresh water forms were found. At Paparý both fresh and salt water forms were found in the lake. The lake in this case, although dammed at the mouth by sand, has at present a direct connection with the sea. It is hard to see, in the case of Logoa Extremoz, how fish can ever get out or how they have existed, being away from the sea apparently for so many years. It is evident that at times of great floods the lake must connect with the ocean.

This damming in of fresh water is a common occurrence along the coast but not always on such a large scale. Paparý, which is farther down the coast, is a river basin partly dammed in by dunes at its mouth and made into a lake.

[6] E. C. Starks, "The Fishes of the Stanford Expedition to Brazil," p. 3. Stanford University, March 17, 1913.

The gaining of the dunes over the river is most probably done in times of drought, for then they can fill the river, cross it, and be carried into the valley.

Economic Geology.

Building Stone.

The crystalline series of rocks contains good building stones, such as granites. Far into the interior there are marbles, but they are rather inaccessible now. Granite is now quarried at Macahyba by the method of cooling the rocks suddenly by throwing water on them after they have been heated by fire. On account of the scarcity of large timber and its rapid decomposition due to climatic conditions and the work of such insects as ants, building stone is an important factor. The ordinary houses are usually made of mud with a reënforcement of slender limbs of shrubs and trees.

Lime.

The limestone series affords a means of making lime and cement. It is quarried where it is found exposed at the surface, but could be obtained at many other places if sought for. The quarries contain bedded rocks of varying economic value. Some of the beds are mostly siliceous, while others are almost entirely composed of calcium carbonate. Three specimens were dissolved in weak hydrochloric acid and gave the following percentage of insoluble matter, varying from 4 per cent to over 20 per cent.

Locality.	Percentage of Insoluble Matter.
Jacoca	10.5
Masaranduba	3.9
Itapasaroca	20.1

The limestone belt, occurring next to the granitic series, affords a means for obtaining cement to use in the same place in connection with the building stone.

Clay.

The clay in the upper sandstone series is sometimes quite pure. It is the material of which the native huts are made. In some places

the purest clay is used for making pottery and bricks. Ornaments, household utensils, such as vessels for holding water, are made at Santo Antonio and at Barreiros. These vessels are red-brown in color and rather easily broken. They appear to have been patterned after Indian styles, which may be a result of the Indian blood in some of the people of this region.

Soils and Agriculture.

The distribution of plants in this region is very striking; they are dependent upon both soils and climate. Thus the rubber tree and other shrubs grow over the sandy plateau region. Farther into the interior the region is arid, almost a desert. Here the soil is of decomposed granites and other crystalline rocks, and cacti and desert shrubs are the principal plants.

Bordering the great valleys, in the old alluvial flats, the *carnahuba* palm is the prominent tree, although this region produces many other plants more or less intergrown. Occasionally forests of trees as high as twenty meters may be found in these old filled-in valleys, as the forest between Monte Alegra and Desterro.

The mangrove swamps are typical of the borders of the estuaries and streams. Here deep black mud is deposited. This alluvium is what makes the fertile soil.

Along the beach one might suppose that there was no vegetation, but on the shores of almost every little cove there is a grove of cocoanut palms and a little fishing village.

The valleys contain a great deal of sand, but are on the whole fertile. The natives use the most primitive methods in farming. There was not a single plow seen about Natal. The soil contains enough sand to keep itself fairly loose and the plants are simply stuck in the ground and left there. Bananas, sugar-cane, cotton, corn, and various kinds of tropical fruits are raised. Occasionally coffee bushes are grown in the shade of other trees. Mandioca is raised in great abundance. Its root is made into farinha, the principal food of the common people.

At Carnahubinha there is a cotton-seed oil factory. Also at this place salt is concentrated from the sea water which flows up the Jundiahy at high tide.

Water-Supply.

The abundant rains along the coast sink into the sand immediately, but on coming in contact with the clayey beds of the sandstone series below, they are not able to pass farther down, so they emerge at low places. These low places are often between sand-dunes. Thus along the sea-coast, natives draw water from holes dug in the sand and the water is soft and fresh.

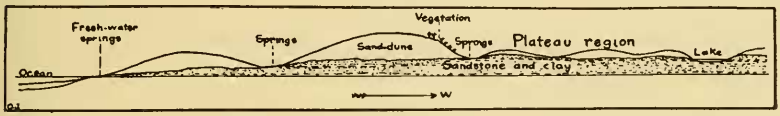

FIG. 12. General section of the coastal sand-dunes, showing how the fresh-water springs occur. Rain sinks through the sand-dunes and emerges where impervious beds of the clayey sandstones are exposed.

On the opposite side of the river from Carnahubinha there is a place called *Agua Doce*. Here excellent drinking water is obtained. The sand-dunes form an amphitheater around one side of the small depression, which is about fifty meters across. The water is bubbling up all the time and carries away the sand as fast as it is blown into it. Fresh water occurs in a certain point in the river near this place, although the river carries salt water from the sea. Here it is said that a hole twenty-two meters deep is present, while the rest of the stream has only the depth of six meters.[7] Similar holes usually occur near the bank where a sand-dune is present.

This form of spring supplies the small lakes of the plateau region with water the year around, as in the region north of Paparý. Here, along the border of some of the lakes, such as Logoa Bom Fim, such springs were found feeding the lake directly.

The rivers carry the water down from the interior. Often they are dammed at their mouths and form lakes. These lakes are valuable to the people, whose villages are clustered about their shores, as at Paparý.

Farther into the interior the lack of water is a serious matter. Sometimes great droughts drive the inhabitants from the country.

[7] Information obtained from Mr. J. D. Smith at Carnahubinha.

The occurrence of granitic rocks does not afford the means of obtaining underground water as in the region of the sedimentaries along the coast.

Effects of Climate, Etc.

All the ocean currents and the winds constantly sweep up the coast towards the northwest. The water is warm and the atmosphere balmy. The greatest rains and the hottest weather occur during the months of our winter. During our summer the rains are more scarce and the atmosphere cooler and drier. The region about Natal does not have such heavy rains as some of the other parts of Brazil such as those nearer the equator. In fact the country about Natal is very healthful.

The direction of the winds and the ocean currents affects the coast line in that all the bars, spits, reefs, and promontories tend to point up the coast to the northwest.

The stone reef at Natal affords the maintenance of a quiet harbor.

Effect of a Sunken Coast.

A sunken coast affords fine harbors. Cities occur at the points where arms of the sea extend up the river channels. Natal is a good example of such a city beside a harbor thus formed. The tides which flow up and down these channels give to the people an easy method of transportation.

Effect of Silting.

A constant annoyance to the people is the perpetual silting up of the channels and the shifting of sands and the formation of sand bars in their harbors. These things change rapidly, being dependent largely on the amount of rainfall, the flow of the rivers, and the intensity and direction of local currents.

Mangroves help the silting process to a great degree, but still these swamps when drained finally make up the fertile lands of the country.

The depth of the silt in the river channels often causes disturbance to the people when they attempt to drive piles in the mud and cannot find bed rock.

Summary.

There are three principal series of rocks in the region about Natal: the particolored sandstones and clays, exposed as sea-cliffs; the underlying fossiliferous beds of limestone; and the crystalline rocks in which are schists, gneisses, quartzites, shales, granites, etc. The sedimentaries form a belt along the coast about thirty kilometers wide, while the crystalline rocks make up the interior country. Besides these formations the alluvial deposits in the valleys and the wind blown sands of the coast are important features of the geology of this region.

The most important results from this work are as follows:

1. The determination of an unconformity between the particolored sandstone and clay series and the underlying limestones.

2. The finding of fossils in the limestones.

3. The determination that the limestones were laid down as estuarine deposits, thus indicating a sunken coast at that time such as exists now.

4. The proof that the coast has sunken recently, and the commercial effect that this condition has had upon the country in affording fine harbors, and in making good agricultural land by the deposition of silt in the rivers forming fertile valleys.

5. The effect wind blown sand has upon the country in damming streams and thus forming fresh-water lakes.

6. The large supply of good water in the region of the sedimentaries in comparison to the lack of water in the dry interior.

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Explanation of Plate XX.

Fig. 1. *Corbula* (?) sp. ind. Drawing from a wax mold.

Fig. 2. *Cardium soaresanum* Rathbun. Composite drawing from several wax molds.

Fig. 2*a*. *Cardium soaresanum* Rathbun. Showing inside cast of shell.

Fig. 3. *Ostrea* (?). Drawing of an impression of the shell.

Fig. 4. *Cerithium* (?) sp. ind. Drawing from a wax mold.

Fig. 5. *Cerithium* (?). Drawing from a wax mold.

Fig. 6. *Turritella natalensis* n. sp. Composite drawing from several wax molds.

Fig. 6*a*. *Turritella natalensis* n. sp. Showing inside cast of shell.

Fig. 7. *Turritella* (?) *jacoquea* n. sp. Composite drawing from several wax molds.

Fig. 7*a*. *Turritella* (?) *jacoquea* n. sp. Showing inside cast of shell.

Fig. 8. *Cerithium* (?) *mirimense* n. sp. Composite drawing from several wax molds.

Fig. 8*a*. *Cerithium* (?) *mirimense* n. sp. Showing inside cast of shell.

Fig. 9. *Natica* (?). Outline of the impression of the shell.